

**RESYNCHRONIZATION OF CONTROL AND DATA PATH
STATE FOR NETWORKS**

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to switching mechanisms for networks, and in particular to reconnection of network channels.

DESCRIPTION OF THE PRIOR ART

Global networks are common to all of today's telecommunication and other network systems, wherein various data, optical, and wireless devices are interconnected by a series of individual local networks. The networks generally consist of nodes and links, which describe the network topology, and associated attributes which comprise the network data. Furthermore, these networks further contain management systems that must co-ordinate the transmission of data traffic, including voice, video, and data, and other information over a variety of transmission mediums, such as wireless, copper, and fiber optic lines.

Many of today's telecommunication networks are in nearly continuous use and can ill afford instances of "down" or "off-line" time in the event of network element failure or maintenance and update procedures. Furthermore, telecommunication networks increasingly require control software and hardware that should have little or no scheduled down time. However, these same network systems require cost effective computing solutions, open architecture for supporting a variety of hardware and software formats, and the flexibility to implement the latest software and hardware updates as they become available. Accordingly, it is critical in today's telecommunication networks to provide and maintain the integrity of data communication in the event of disruption in the control and data flows, due to both anticipated and unanticipated interruptions.

1 Modern telecommunication networks and their support systems have evolved from static
2 installations to dynamic systems, which need to implement and adapt to changes on a regular
3 basis. These dynamic systems increasingly contain new collections of products that process a
4 plurality of requests from a constantly changing user base, in an expected reliable environment.
5 The ability of telecommunication networks to provide stable service availability in this dynamic
6 environment is becoming increasingly important, as the innovation in products and customer
7 environments is expected to increase.

8
9 In traditional networks, control flow and data flow were coupled for communication
10 traffic between various network elements. Accordingly, it was typical that both the data and
11 control flows failed at the same time during network interruptions. However, today's
12 telecommunication networks are characterized by the separation of the control and data flows, as
13 the data channels and their operation are somewhat independent from the control channels and
14 their associated software controllers. For example, in optical switches, the lasers and other
15 optical elements can continue to transmit data even in the event that their corresponding optical
16 connection controller experiences either line or module failure. Therefore, during failure events
17 the data channels and control channels can become unsynchronized, such that rather than both
18 being maintained in "up states" their states may alternate between unsynchronized up and down
19 modes of operation. These mismatched operational states of the network for the data and control
20 channels need to be resynchronized in a straightforward and efficient manner, so that the
21 perception of network interruptions by the customer is minimized. Accordingly, during recovery
22 or replacement of network elements the network is expected to resynchronize its state such that
23 the new signaling element knows about the data elements that were previously allocated.

24
25 One traditional method of re-synchronization is the journaling technique. Accordingly, at
26 each network element the journaling technique continuously journals (copies) the pertinent state
27 information from the signaling element, such as control instructions and corresponding switch
28 settings, on to spare hardware such as standby signaling elements or to a data element.
29 Therefore, in the event of a network failure the new controller, software and/or hardware, can
30 recover its state by accessing the journal by querying the data element, or if kept in sync by

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1 simply restarting. However, this resynchronization method requires dedicated spare hardware
2 for backup storage purposes. Furthermore, the operational speed for such journalling systems is
3 slower as the state information must be stored as it is created and/or changed in the network, and
4 correspondingly these journal copies must be deleted when these network connections are
5 removed. A further disadvantage of the journaling technique is in the deployment of new or
6 enhanced hardware/software, which should be compatible with the old versions on the backup
7 hardware. Further, these new deployments or enhancements must also be journaled, as well as
8 any changes to the copying/journaling protocols resulting from related control protocol
9 modification. Accordingly, implementation of software and hardware updates over the network
10 can be time consuming and problematic, when relying on the journaling technique for network
11 reliability.

12
13 It is an object of the present invention to provide a resynchronization method and system
14 to obviate or mitigate some of the above-presented disadvantages.

15 16 SUMMARY OF THE INVENTION

17
18 The present invention employs a network switching protection system for creating and
19 removing network connections, to recreate connection states after a failure has occurred in
20 network paths between interconnected network elements. The network paths are traditionally
21 organized in control layers and in line layers of the network. The switching system can store the
22 connection state of the entire paths of the network in a resynchronization table coupled to the
23 head end controller of the network, in a localized or distributed fashion. After a control element
24 failure, network signaling mechanisms are used to repopulate the connection states from a
25 localized location, such as a controller at the connection head end, and are used to recreate the
26 failed paths and carry the corresponding connection state information back to all of the control
27 elements along these paths. Furthermore, when there is a failure in the control network paths but
28 the corresponding data network paths continue to operate, the head end controller receives an
29 indication that there has been a control path failure as distinguished from a data path failure.
30 Accordingly, after the data path failure is detected, each of the controllers concerned query the

1 exact connection states of all of their connections in their corresponding network elements and
2 attempt to re-create them, using the actual data path gathered from their stored data path
3 connection states located in the resynchronization table. The present protection switching
4 system can be used in the event of multiple controller failure when the controllers are
5 subsequently re-booted. In this case, the network will continue to carry the data traffic along the
6 active data path. When the controllers are re-started, the controllers re-learn all of their
7 connection states through a set-up message populated by the accumulated connection state data
8 contained in the resynchronization table. This set-up message provides the associated controllers
9 with the connection state information used to continue managing the line layer paths that are
10 already operating on their respective cross connects, and to be able to manage new connections
11 as required. The protection switching system also provides for re-booting in the event of failures
12 for network paths in the line layer, which occurred while portions of the control layer were
13 down. Accordingly, resynchronization in this double failure environment is facilitated through
14 the use of the message populated by the connection state data stored in the resynchronization
15 table, which is accessible and communicated by the head controller along the corresponding
16 network paths.

17
18 According to the present invention there is provided a network protection switching
19 system for resynchronizing network communication between a line layer and a control layer after
20 identification of a network failure. The system comprises: a resynchronization table for storing a
21 plurality of connection states corresponding to a plurality of interconnected network elements,
22 the interconnected network elements forming a network path in the line layer of the network.
23 The system also comprises an interface for providing access of a first controller to the connection
24 states of the resynchronization table, the first controller included in the control layer which is
25 coupled to the line layer for monitoring network traffic communicated therein, wherein
26 resynchronization of the line layer and the control layer is established after the failure using the
27 first controller to propagate the connection states for use by other controllers of the control layer.

28
29 According to a further aspect of the present invention there is provided a controller
30 configured for monitoring the resynchronization of network communication

1 between a line layer and a control layer after identification of a network failure. The controller
2 includes: the controller linkable to the control layer of the network, the control layer for
3 monitoring network traffic communicated in the line layer. The controller also includes a
4 controller interface for providing access to a resynchronization table, the resynchronization table
5 for storing a plurality of connection states corresponding to a plurality of interconnected network
6 elements, the interconnected network elements forming a network path in the line layer of the
7 network, wherein resynchronization of the line layer and the control layer is established after the
8 failure using the controller to propagate the connection states for use by other controllers of the
9 control layer.

10
11 According to a still further aspect of the present invention there is provided
12 resynchronization method for networks for re-establishing communication between a line layer
13 and a control layer in the event of a failure. The method comprising the steps of defining a
14 plurality of interconnections between network elements contained in the line layer to generate a
15 network path; accumulating a plurality of connection states for the interconnected network
16 elements of the network path; storing the connection states by populating a resynchronization
17 table, the resynchronization table coupled to a first controller of the control layer; and providing
18 the connection states of the resynchronization table to the controllers of the control layer in the
19 event of the failure for resynchronization of the line layer and the control layer.

20
21 According to a further aspect of the present invention there is provided a computer
22 program product for re-establishing communication between a line layer and a control layer in
23 the event of a failure in networks. The product comprising a computer readable medium; a line
24 layer module stored on the computer readable medium for defining a plurality of
25 interconnections between network elements contained in the line layer to generate a network
26 path; an accumulator module coupled to the line layer module for gathering the connection states
27 for the interconnected network elements of the network path once defined; a resynchronization
28 table module coupled to the accumulator module for storing the connection states for access by a
29 first controller of the control layer; and a message module for providing the connection states of

1 the resynchronization table to the controllers of the control layer in the event of the failure for
2 resynchronizing the line layer and the control layer.

3 4 BRIEF DESCRIPTION OF THE DRAWINGS

5
6 These and other features of the preferred embodiments of the invention will become more
7 apparent in the following detailed description in which reference is made to the appended
8 drawings by way of example only wherein:

9 Figure 1 is a diagram of a Global Network;

10 Figure 2 is a diagram of a local network of Figure 1;

11 Figure 3 shows a failure protection switching system of Figure 2;

12 Figure 4 is an operational flowchart of the system set-up of Figure 3;

13 Figure 5a shows a tandem controller failure for the network of Figure 3;

14 Figure 5b shows further failure details of Figure 5a;

15 Figure 6 shows a simultaneous control and data path failure for the network of Figure 3;
16 and

17 Figure 7 is an operational flowchart of the failure mode for the network of Figure 6.

18 19 DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 Referring to Figure 1, a global telecommunication Network 10 contains a series of sub-
21 networks An, Bn, Cn, Dn, En interconnected by bulk data transmission mediums 12. These
22 mediums 12 can consist of such as but not limited to optical fiber, wireless, and copper lines
23 which can be collectively referred to as the Backbone Network. Each sub-network An, Bn, Cn,
24 Dn, En contains a plurality of network elements 14 interconnected by conduits 16, also referred
25 to collectively as a control layer 15 and a line layer 17 (see Figure 2). These conduits 16 can
26 consist of fiber optic cables, DSL (Digital Subscriber Loop), cable, and wireless mediums,
27 wherein each conduit 16 can be capable of providing the transmission of multiple wavelengths or
28 signals 18 as required by the telecommunication network 10. The transmission structure of the
29 telecommunication network 10 can be used by a variety of different carriers, such as ILECs,
30

1 CLECs, ISPs, and other large enterprises to monitor and transmit a diverse mixture of data
2 packets 20 in various formats. These formats can include voice, video, and data content
3 transferred over the individual SONET, SDH, IP, WDN, ATM, and Ethernet networks associated
4 with the telecommunication network 10.

5
6 Referring to Figure 2, the subnetwork En includes each network element 14
7 interconnected by a series of conduits 16 referred to as a data path 34, which collectively
8 comprise the line layer 17. The line layer 17 can be monitored by a central computerized
9 management system 22, which for example co-ordinates a plurality of connection requirements
10 24 received from clients 26 connected to the sub-network En. The clients 26 or other peripheral
11 devices can include such as but not limited to hubs, leased lines, IP, ATM, TDM, PBX, and
12 Framed Relay PVC. Coupled to each network element 14 is a controller 28, which co-ordinates
13 the connection and data requests 30 to each of their corresponding network elements 14. This
14 association of controllers 28 is also referred to as the control layer 15, which has a complete
15 picture of their corresponding network element 14 interconnections, as interconnected by a series
16 of conduits 16 referred to as a control path 32. The control path 32 can receive data management
17 and other network state information 36 from the management system 22.

18
19 The management system 22 can include a processor 25, which is coupled to a display 27
20 and to user input devices 23, such as a keyboard, a mouse, or other suitable devices. If the
21 display 27 is touch sensitive, then the display 27 itself can be employed as the user input device
22 23. A computer readable storage medium 21 is coupled to the processor 25 for providing
23 instructions to the processor 25 to instruct various controllers 28 and corresponding network
24 elements 14 to perform steps or algorithms related to the operation of a protection switching
25 mechanism 31 (see Figure 3) implemented on the subnetwork En, in the event of a network
26 failure as given below. The computer readable medium 21 can include hardware and/or software
27 such as, by way of example only, magnetic disks, magnetic tape, optically readable medium such
28 as CD ROMs, and semi-conductor memory such as PCMCIA cards. In each case, the computer
29 readable medium 21 may take the form of a portable item such as a small disk, floppy diskette,
30 cassette, or it may take the form of a relatively large or immobile item such as hard disk drive,

1 solid state memory card, or RAM provided in the management system 22. It should be noted
2 that the above listed example computer readable mediums 21 can be used either alone or in
3 combination. Accordingly, the protection switching mechanism 31 can be implemented on the
4 subnetwork En in regard to the co-ordination of the maintaining synchronization between the
5 data paths 34 and the control paths 32, in the event of network failures, in the line layers 17 and
6 control layers 15 respectively.

7
8 In reference to Figure 3, a simplified version of the control layer 15 and the line layer 17
9 is given for clarity purposes only. The subnetwork En consists of four pairs of controllers 28
10 referred to individually as C-1, C-2, C-3, C-4 (collectively referred to as Cn) and network
11 elements 14 referred to individually as cross connects DX-1, DX-2, DX-3, DX-4 (collectively
12 referred to as DXn). The control layer 15 contains some of the general state information 36 (see
13 Figure 2) received from the management system 22 distributed amongst the controllers Cn. The
14 controllers Cn have a subset of local state information 44 obtained from the general state
15 information 36, and associated with the data path 34, as well as additional end to end information
16 not present in the line layer 17. For example, C-1 and C-2 will have assigned logic channel
17 numbers 45 to their shared control path 32, and will have created the control path 32 based on
18 these logical channel numbers 45 for the purpose of end to end signaling. Further, additional
19 state information from the general state information 36 is stored by C-1 and C-4 to represent the
20 end points of the connections 32. These end points consist of a number of process objects 48
21 with their respective data, which can include from top to bottom, such as but not limited point
22 information, call controller information, virtual circuit information, networking connection
23 information, and application connection information.

24
25 The local state information 44 of the general state information 36 present in the line layer
26 17 can contain, for example see Figure 3, an STS-1 signal arriving at DX-1 on logical port 7,
27 time slot 33, depicted as 7[33]. Cross connect DX-1 connects the signal to logical port 9 time
28 slot 6, depicted as 9[6]. The cross connect information 7[33] x 9[6] represents the state that the
29 cross connect DX-1 must remember to keep the connection alive. When the signal arrives on the
30 cross connect DX-2, it arrives on logical port 4 time slot 6, depicted as 4[6]. Note that the

1 logical port numbers can be different for the same fiber pair between adjacent cross connects
2 DXns, for example 9[6] is the same as 4[6] between cross connects DX-1 and DX-2. The cross
3 connects DXn of the line layer 17 also contain switch fabrics 38 and corresponding control units
4 40 for coordinating traffic data following from port 41 to port 41, as is known in the art.
5 Accordingly, the switch fabric 38 of each cross connect DXn is connected to the corresponding
6 plurality of ports 41. The switch fabric 38 also couples the ports 41 such that the data packets 20
7 (see Figure 1) received on one of the ports 41 is output for another of the ports 41. The control
8 unit 40 of the cross connects DXn is connected to the switch fabric 38 and monitors the adjacent
9 conduits 16 of the data path 34 for failure detection.

10
11 The protection switching system 31 includes storage of selected portions of the local state
12 information 44 in a network path state or resynchronization tables 46, which is coupled or
13 otherwise interfaced to the head end controller C-1 of the control path 32. The interface can
14 include a series of pointers to the local state information 44 stored in the resynchronization tables
15 46, or other hardware/software messaging elements providing access of the head end controller
16 C-1 to the stored local state information 44. Accordingly, during the initial Set-up and Query
17 messaging to construct the data path 34, such as the 7[33] - 72[43] path of Figure 3, the exact
18 sequence of logical ports and time slots is queried and accumulated to generate the
19 resynchronization table 46. As part of the normal set-up of the network data path 34, the local
20 connection state information 44 is queried for all hops, and then the gathered local state
21 information 44 can be carried back to populate the resynchronization table 46. This can be
22 accomplished by modifying the network gather message used in telecommunication network 10,
23 so that the message can gather the required information in the reverse flowing message direction
24 as it returns back from cross connect DX-4 towards the head end cross connect DX-1,
25 completing the data path 34 set-up. Accordingly, the resynchronization table 46 can be
26 represented for example by CON/1={7[33],9[6],3[7],6[4],72[43]} for the data path 34 of Figure
27 3. It is recognized that the above Set-up and Query algorithm may be selectively enabled on a
28 per connection basis, as desired in configuration and maintenance of the telecommunication
29 network 10.

1 Once the local state information 44 for the resynchronization table 46 arrives back at the
2 head end cross connect DX-1, this resynchronization table 46 is then stored locally at the head
3 end controller C-1, and can also be shadowed at a number of locations such as but not limited to
4 the head end cross connect DX-1 as a back up in case the head end controller C-1 fails. This
5 storage can be accomplished by journaling the contents of the resynchronization table 46 where
6 it can be recovered by the head end controller C-1 after a failure, such as being stored on disk,
7 non-volatile RAM, or its own data elements. It should be noted that the resynchronization table
8 46 stored on cross connect DX-1 can be independent of the cross connect information (i.e.
9 4[6]x3[7], 2[7]x6[4], 8[4]x72[43]), however cross connect information could also be stored in the
10 resynchronization table 46 as well if desired. However, it is recognized that deleting the cross
11 connect information so that the resynchronization table 46 only contains the local state
12 information 44 can help the resynchronization table 46 to be independent of the act of
13 programming from the act of storing for greater network flexibility. Furthermore, it is
14 recognized that the resynchronization table 46 is preferably accessible so as to be
15 read/written/deleted in whole or in parts as required, as the network En dynamically changes in
16 connection architecture.

17
18 In regard to Figures 3 and 4 for operation of the protection switching system 31, the
19 controllers 28 receive the connection and data traffic connection requirements 24 initiated by the
20 client 26 at step 100. The head controller C-1 then notes the desired end to end connection
21 request 7[33]-72[43] and sends the initial set-up message at step 102 along the selected control
22 path 32, including associated tandem controllers C-2, C-3 and end controller C-4. Accordingly,
23 the controllers Cn request 30 their respective cross connects DXn to configure the switch fabric
24 38 of each cross connect DXn at step 104, and the exact sequence of logical ports and time slots
25 is queried 106 and sent as a reverse flowing message back to the head controller C-1. The local
26 state information 44 is used to populate 108 the resynchronization tables 46 at step 110, which is
27 then accessible by the head controller C-1. Preferably, a back-up copy of the resynchronization
28 table 46 is shadowed at an auxiliary site, such as but not limited to the corresponding cross-
29 connect DX-1. In subsequent operation of the subnetwork En, the local state information 44 of
30 the resynchronization table 46 can be modified 112 in the event of dynamic connection state

1 modification in the subnetwork En, such as but not limited to creation or removal of connections
2 between ports 41 in the data channel 34. Otherwise, the requested data packets 20 are
3 transmitted over the data channel 34 absent any network failures.

4
5 Traditionally, there are two types of failures that can be experienced in the subnetwork
6 En, such as line failures and module failures. The basic subnetwork structure En consists of
7 various links situated between corresponding transmitters and receivers of cross connects DXn,
8 which can also be referred to as network elements 14. Accordingly, a line failure can include
9 damage to the physical fiber 18 and optical components, such as the malfunction of amplification
10 equipment situated along an optical data path 34. In contrast, the module failure can consist of
11 inoperable transmission or reception equipment, such as a broken laser diode transmitter or
12 controller module. It should be noted that both line failures and module failures may disable the
13 logical and/or physical interconnection between two network elements 14. Preferably, the
14 protection switching system 31 has the ability to distinguish between control path 32 and data
15 path 34 failures, wherein control path 32 failures do not interrupt local state information 44 but
16 leave the physical connections represented by the local state information 44 as ownerless.

17
18 Referring to Figures 5a and 5b, a pure tandem failure 48 is shown, which could be caused
19 for example by controller C-3 experiencing a short outage due to unplugging and plugging in
20 new hardware. Referring to Figures 5a, 5b, control messages Sn are transmitted in the control
21 layer 15 using data requests 30 and the control path 32 to implement the failure switching system
22 31. Firstly, control messages S-1 and S-2 note the failures of the signaling links between
23 controllers C-2 and C-4 with downed controller C-3, with a reason denoted as "signaling
24 failure". At each point along the way, the logical ports/time slots represented by the local state
25 information 44 used by the path data 34 are marked as "disowned", as the actual control
26 connection represented by the data path 34 is collapsed. Therefore, the ingress/head end
27 controller C-1 receives the tear control message S-1 and notes the reason is due to the signaling
28 failure. It should be noted that the controller C-4 does not receive the recreate control message
29 S-5, as controller C-3 cannot propagate received control messages Sn. The local state
30 information 44, through retrieval control message S-4, is communicated to the controller C-1 and

1 placed in control message S-5, which is used to send the local state information 44 as
2 path={7[33],9[6],3[7],6[4],72[43]} using the obtained sequence of logical ports and time slots
3 from the resynchronization table 46 along the control path 32. As a result, controller C-1 queries
4 the resynchronization table 46 through control message S-3 for the local state information 44 that
5 represented failed data path 34. Accordingly, at some point controller C-3 will come back on-
6 line and the set-up control message S-5 will propagate through to the end controller C-4, at
7 which point the logical ports and time slots represented by the local state information 44 on C-1,
8 C-2, C-3, and C-4 will be re-established and moved from the disowned to owned state. It is also
9 recognized that the head end controller C-1, when it receives the tear control message S-1 due to
10 the signaling failure, proceeds to query by control message S-3 the cross connect DX-1 for the
11 local state information 44 contained in resynchronization table 46. However, the head end
12 controller C-1 can also keep a shadow copy of the resynchronization table 46 to avoid the CCI
13 overhead of such a query of control message S-3. It should be noted that another controller Cn
14 or cross connect DXn can initiate the set-up control message S-5, if desired.

15
16 In regard to the operation of tandem controller C-3, under failure 48, reference is made to
17 Figure 5b. Accordingly, when tandem controller C-3 has restarted, it is not aware of all of the
18 local state information 44 concerning the currently disowned state 2[7]x6[4]. As a result, after
19 restarting, the tandem controller C-3 first queries and assigns the logical ports to the
20 corresponding control path 32. Then, the tandem controller C-3 queries by control message S-6
21 the state connections that are currently resident on its corresponding cross connect DX-3, and
22 then stores the local state information 44 represented by 2[7]x6[4] using the control message S-7.
23 Subsequently, when the set-up control message S-5 reaches the re-started tandem controller C-3,
24 tandem controller C-3 notes that it should now claim ownership of the disowned state of
25 2[7]x6[4], thereby re-establishing control of the complete data path 34. Preferably, in situations
26 where re-started controllers Cn do not receive the set-up control message S-5 after re-starting,
27 these controllers Cn completely release their disowned connection states contained in the local
28 state information 44 in a predetermined number of minutes, such as but not limited to 10
29 minutes. This occurs also if the disowned state represented by the local state information 44 is
30 not re-claimed by the explicit logical ports/time slot set-up according to the control message S-5.

1 It is noted that the end controller C-4 also receives the control message S-5 when the tandem
2 controller C-3 is restarted, and acts to reclaim the connection state of the local state information
3 44 resident on the cross connect DX-4.

4
5 In the event of the failure 48 occurring on the head controller C-1, one tear control
6 message S-1 is propagated from the tandem controller C-2 to the end controller C-4, indicating
7 the failure 48. Accordingly, the data control path 34 is collapsed and the connections
8 represented by the local state information 44 are disowned for cross connects DX-2, DX-3, and
9 DX-4. However, in the present case, the head end controller C-1 must then re-claim both its
10 resynchronization table 46 of disowned local state information 44 and a local copy of the
11 resynchronization table 46 prior to re-setting up its provisional connections according to the local
12 state information 44. It is recognized that when the provisional connections are being set-up, a
13 check is made to see if there is a current data base entry with a path for this connection in the
14 local state information 44 recorded in the resynchronization table 46. Accordingly, if one exists
15 then this is used. At this stage, the control messages S-3 and S-4 are used to generate the set-up
16 path control message S-5 down the control path 32. In this case, the controller C-1 first takes
17 ownership of its disowned connections and then controllers C-2, C-3, and C-4 reclaim their
18 corresponding connections on cross connects DX-2, DX-3, and DX-4 respectively, using control
19 messages S-6 and S-7. It is further recognized that the time-out protocol could also be used
20 when the failure 48 occurs at the head controller C-1.

21
22 Referring to Figure 6, a simultaneous data path 34 and control path 32 failure is shown.
23 Accordingly, the tandem controllers C-2 and C-3 initiate tear down control messages S-1 and S-
24 2, thereby disowning the local state information 44 representing connections of data path 34.
25 Correspondingly, control messages S-15 from the cross connects DX-2, DX-3 are also relayed to
26 their corresponding tandem controllers C-2, C-3 for notification to the subnetwork En. Next,
27 head controller C-1 retrieves the stored resynchronization table 46 using control messages S-3,
28 S-4 for retrieving the port and time slot information, for use in generating the set-up path control
29 message S-5, which contains for example the information (7[33],9[6],3[7],6[4],72[43]).
30 However, controller C-2 after receiving the set-up control message S-5 sends a further tear

1 control message S-8 telling the head controller C-1 that the control path 32 is broken at failure
2 50. Controller C-2 then proceeds to delete the local state information 44 from its corresponding
3 cross connect DX-2 using control message S-9, and waits for further set-up path local state
4 information 44 transmitted by the head controller C-1. Correspondingly, the head controller C-1
5 also deletes its local state information 44 using control message S-10 and further deletes the
6 corresponding resynchronization table 46 containing the outdated exact series of port and time
7 slot information for the failed control path 32, using control message S-11. Subsequently, the
8 head controller C-1 obtains alternate local state information 44 from the resynchronization table
9 46 and propagates this along alternate control and data pathways 32, 34 for re-establishment of
10 the required network connection using set-up re-dial path control message S-12. It should be
11 noted in the event that failure 50 is not repaired, then controllers C-3 and C-4 continue to operate
12 independently with disowned connections until a time out occurs after a predetermined period of
13 time, upon which controllers C-3 and C-4 send respective control messages S-13 and S-14 to
14 delete their disowned local state information 44 resident at cross connects DX-3, DX-4
15 respectively.

16
17 Referring to Figures 6 and 7, operation of the failure mode of the protection switching
18 system 31 and associated subnetwork En follows below. After the resynchronization table 46
19 has been set-up, the subnetwork En continues to operate 116 until the failure 48, 50, 52 is
20 detected at step 118. The functioning controllers Cn receive the failure control messages S-1, S-
21 2 and the corresponding data path 32 is collapsed, thereby disowning the connection resident in
22 the cross connects DXn. The head controller C-1, or replacement if needed, then accesses the
23 resynchronization table 46 information at step 122 and generates 124 the set-up path signal S-5
24 along the control path 32, which is propagated to the end controller C-4 once all the controllers
25 Cn are restarted. In the event that head controller C-1 is not available 126, the head controller is
26 restarted at 127 and a stored copy of the resynchronization table 46 is retrieved 128 prior to
27 generation of the control message S-5. In the event the failure is recoverable at step 130, then
28 the controllers Cn wait to be restarted 148 before resynchronizing with their corresponding cross
29 connects DXn, by reclaiming disowned states 146 as identified by the set-up control message S-
30 5. Accordingly, the subnetwork En is re-synchronized and returns to normal operation mode

1 116.

2
3 However, in the event of an unrecoverable control/data failure 50, 52 being detected at
4 step 130, the resynchronization table 46 data is deleted at step 132 and the controller C-1 tries to
5 set-up 134 an alternate data path 34 with control message S-12. In the event an alternate data
6 path 34 is established 136, the new set-up resynchronization table 46 is populated (as described
7 in Figure 4) at step 138 and the subnetwork En is operated as directed by client requests 24 and
8 the data packets 20. However, if the alternate data path 34 can not be established at time-out step
9 140, either retries are attempted for control message S-5 at step 124 or an alarm time-out 144 is
10 transmitted for resolution by the management system 22.

11
12 The switching protection system 31 of the present invention provides a system and
13 process for using mechanisms for creating and removing network connections represented as
14 local state information 44 in the resynchronization table 46 to re-create connection states after
15 the failure 48, 50, 52 has occurred. This switching protection system 31 can store the
16 resynchronization table 46 of the entire data path 34 of the subnetwork En of interconnected
17 network elements 14 at the head end controller C-1 of the subnetwork En. After the control
18 element failure has occurred, signaling control messages Sn are used to populate the local state
19 information 44 from the controller C-1 and are used to re-set-up the failed data path 34 and carry
20 the corresponding local state information 44 back to all of the control elements Cn along this
21 data path 34. Furthermore, when there is the failure in the control path 32, but the data path 34
22 continues to operate, the head end controller C-1 receives an indication that there has been the
23 control path failure 48, 50 as distinguished from the data path failure 52. Accordingly, after the
24 failure, each of the controllers Cn query the exact states of all of their connections in their
25 corresponding cross connects DXn and attempt to re-create them, using the actual path of their
26 stored data path states is the resynchronization table 46. The present protection switching system
27 31 can be used in the event of multiple controller Cn failures, which are subsequently re-booted.
28 In this case, the subnetwork En will continue to carry the data packets 20 and when the
29 controllers Cn are re-started, the controllers Cn re-learn all of the local state information 44
30 through the set-up control message S-5 populated by the accumulated local state information 44

1 contained in the resynchronization table 46. This set-up control message S-5 provides the
2 associated controllers Cn with the local state information 44 used to continue managing the data
3 paths 34 that are already operating on their respective cross connects DXn, and to be able to
4 manage new connections as required. The protection switching system 31 also provides for re-
5 booting in the event of failures in the line layer 17 that occurred while portions of the control
6 layer 15 were down. Accordingly, resynchronization in this double failure environment is
7 facilitated through the use of the control message S-5 populated by the local state information 44
8 stored in the resynchronization table 46, which is coupled to the head controller C-1.

10 In addition, the protection switching system 31 can also manage planned outages of the
11 controllers Cn, or associated signaling cards for the purposes of software upgrade or major
12 configuration changes. Accordingly, the control layer failure 48 can be attributed by either an
13 operational failure or a failure for upgrade reasons. It is recognized that the local state
14 information 44 can also be stored in parts as multiple distributed resynchronization tables 46.
15 Accordingly, the head controller C-1 can access these multiple locations of the resynchronization
16 table 46, thereby obtaining a complete picture of the distributed network of local state
17 information 44 of the data path 34. It should also be noted that the resynchronization table 46
18 can be a logical and/or physical entity.

20 In the switching protection system 31, the protection protocol given in Figures 4 and 7 is
21 followed to help facilitate the resynchronization of the subnetwork En after the failure has
22 occurred. This protection protocol contains the control messages Sn of the ability to query and
23 store the exact sequence of logical ports and time slots that make up the data path 34, as the
24 resynchronization table 46. The head/ingress end C-1 of the control path 32 can receive the
25 stored local state information 44 during set-up and can store it in both local and in shadow
26 locations. The switching protection system 31 also contains the ability to distinguish between
27 control path 32 and data path 34 failures, as control path 32 failures do not clear cross connect
28 data represented by the local state information 44, but simply leave it "ownerless". The
29 switching protection system 31 also contains the ability to populate the exact sequence of logical
30 ports and time slots accumulated in the definition of the subnetwork En implemented, as the set-

1 up control message S-5 initiated by the head controller C-1 to re-claim "ownerless" cross
2 connections contained on respective cross connects DXn. The switching protection system 31
3 also facilitates the clearing of an "ownerless" local state information 44 after a pre-determined
4 period of time has lapsed.

5
6 It should be noted for the purposes of implementation of the protection switching system
7 31 of the present invention, a network element 14 can be any of the following kinds of devices,
8 such as but not limited to: a SONET cross connect or add/drop multiplexer (i.e. a device that can
9 take input port/fiber/time slot and map to output/port/fiber/time slot). The network element 14
10 can also include a time division multiplexer using mechanisms other than SONET to multiplex
11 data in time that is able to take input port/fiber/time to output port/fiber/time, as well as a
12 Lambda switch or pure photonic switch that can take port/fiber/wavelength input and map it to
13 output port/fiber/time slot. Furthermore, it is recognized that the protection switching system 31
14 can also use any switch capable of moving photons in or out either with or without amplification
15 or wavelength conversion, and can select input port to output port mapping doing a wavelength
16 conversion along the way (i.e. MEMS switches, Bubble switches, or variations based on
17 wavelength filtering techniques). Further, the protection system 31 can also employ switches
18 that operate statistically by the insertion of a header to allow multiplexing and de-multiplexing of
19 the data packets 20. Such switches 14 can take input port/header and map to output port/header
20 (i.e. ATM, MPLS, and frame relay).

21
22 Although the invention has been described with reference to certain specific
23 embodiments, various modifications thereof will be apparent to those skilled in the art without
24 departing from the spirit and scope of the invention as outlined in the claims appended hereto.